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INVESTIGATION OF AN INTERFERENCE PROBLEM WITH THE EMERGENCY POWER GENERATORS AT DARLINGTON NGS

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At Darlington NGS A an interference problem caused the Emergency Power Generator 1 to trip off on start up. The problem involved intermittent chattering of the output of one of the speed monitors used in the generator's control system. An investigation showed that this maloperation was due to noise spikes on the 24-volt dc bus being coupled into the speed monitor's input, thereby generating an erroneous speed signal. This report describes the details of this investigation and outlines possible measures that could be taken to reduce the likelihood of this type of problem recurring. These primarily include the addition of suitable noise filters on the 24-volt bus and the replacement of one particular device found to generate excessive noise on the bus.

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1.0 INTRODUCTION

Following a verbal request by P. Stern of Darlington Engineering, an investigation was made into an interference problem observed with the speed monitors associated with the Emergency Power Generators (EPG) at Darlington NGS. The problem manifested itself on EPG1 as the generation of erroneous trips by the speed monitors in the control circuitry of the turbine driving the power generator. Initial investigation at the site had shown that the erroneous trips were associated with a "spikey" interference or noise signal present at some of the speed monitor inputs, as well as on the 24-Vdc bus supplying the speed monitors. Also, a noise problem was reported to have occurred previously on EPG2 when the vibration monitor was re-installed after being repaired by the manufacturer. The vibration monitor's internal dc/dc converter-type power supply had generated enough 30-kHz noise to cause the control system's "Power Turbine Backup Overspeed" monitor Z353 to react incorrectly. When a capacitor was installed across the 24-volt terminals of that monitor as suggested by the manufacturer, that particular problem had been eliminated.

This report outlines the results of the investigation into this problem. It describes the nature of the interfering noise on the control system wiring, identifies the major sources of the noise and suggests measures for alleviating problems or potential problems due to the noise.

2.0 OUTLINE OF THE EPGs AND THEIR NOISE-GENERATING COMPONENTS

The noise observed on the EPG control system wiring has interfered with the operation of at least two of the six speed monitors. These speed monitors are part of the EPG control systems which are located in a separate building some distance away from the EPG combustion turbines themselves. The EPG control systems are powered by a 24-volt battery which is located in the combustion turbine building. A cable, estimated to be some 300 metres long, connects the control equipment to the battery. The speed signal cables that run from the speed sensors at the turbines to the speed monitors in the control systems follow the route of the dc power cable and are therefore about 300 metres long as well.

Each of the two EPG units has its own separate control system, housed in its own separate cabinet called the "Control Console". Inside each control console the speed monitors are mounted on an upper panel (called the "Digital Panel"), along with a number of relays and terminal blocks. A total of six monitors supervise the speeds of the Diesel, the gas producer and the power turbine.

Also inside the control console, on a lower panel (called the "Analog Panel"), are mounted various dc/dc converter-type power supplies, undervoltage and sync check relays as well as circuit breakers for the various 24-Vdc buses.

The speed monitors are of two different types, the main difference (from the point of view of this investigation) being in the design of their internal power supplies. One version, such as the Z226 Diesel Speed Monitor, uses a simple voltage regulator to set its internal dc supply voltage while the other type, such as the Z253 Power Turbine Speed Monitor, is equipped with a dc/dc converter-type power supply to generate its internal dc supply voltage from the 24-Vdc battery voltage. One advantage of the latter supply is that the speed sensing circuitry is galvanically isolated from the battery. Dc/dc converters are also used in the three power supplies Z200, Z203 and Z205 to convert the 24 Vdc to ± 15 Vdc or 6 Vdc for energizing other electronic equipment in the control console, such as temperature monitors, annunciators, guide vane and bleed valve controller, etc. (Power supply Z204 is not involved in the present discussion as it runs off the 15-Vdc supply, to generate 10 Vdc.)

In the course of normal operation, the foregoing dc/dc converters draw large amounts of current for a very short time followed by longer periods of little current. For these particular converters, this alternating between high and low current occurs at a repetition rate of about 15 kHz. The effect of these current pulses on the supply voltage depends upon the supply impedance. To a large extent this is the reason for the observed noise on the 24-Vdc bus. Although in this case the power source is a battery which usually has a low impedance, the long cable run (about 300 m) connecting the dc/dc converters to the battery introduces sufficient impedance for the current pulses to be converted to significant voltage pulses on the 24-Vdc supply voltage at the control console end. Diode CR4 which is in series with the circuit breaker CB203, as well as CB203 itself, contribute further to this impedance, thereby adding to the voltage noise.

3.0 INVESTIGATION

The investigation centred on identifying the major sources for the noise observed on the EPG control system wiring and determining the mechanism by which the noise caused the malfunction of the Diesel speed monitor. It was hoped that simple effective measures could then be developed for reducing the noise and/or noise sensitivity of the affected devices to prevent another malfunction.

First, the noise observed on the 24-Vdc bus was in the form of voltage spikes having an amplitude typically in the range of 1 to 10 volts peak-to-peak, at a repetition rate of roughly 15 kHz. Frequently there would be more than one such set of spikes superimposed so that the spacing between spikes would be somewhat random.

A similar type of noise was observed on the speed signal input wiring to several speed monitors. The nature of the spikes was the same as that observed on the 24-Vdc wiring although the voltage tended to be somewhat lower, typically in the range of about 0.1 to 2.0 volts peak-to-peak. It was investigated whether this noise was coupled in by adjacent

noisy 24-Vdc supply wiring or via the speed monitors themselves that are energized from the noisy 24-Vdc bus. (This part of the investigation was carried out only on EPG2, although the results should be similar for EPG1.)

In the course of this work it was noted that while both EPG units had considerable noise on the dc supply and signal wiring, the causes for this noise and the effects on the operation were different between the two units. The malfunction in EPG1 was caused by a speed monitor, while on EPG2, although no malfunctions were observed during the investigation, considerable noise was generated by two of the four power supplies. Even if this noise did not seem to be causing problems during the investigation, it represents a potential source of future problems.

The following sections outline the findings observed in the two control systems. Some of the details are recorded in the Appendix for reference purposes.

3.1 Emergency Power Generator No. 1

The noise voltages on the speed signal wires and on the 24-Vdc power wires to the speed monitors were observed using an oscilloscope. It was observed that some wires had noise of the type previously reported from site whereas others were relatively clean. After some experimentation the interference on the speed signal cables was found to originate at the speed monitors to whose inputs they were connected. No interference could be observed on these cables while they were disconnected from their monitors.

During commissioning of EPG1, the Diesel speed monitor Z226 prevented start-up of the EPG. The commissioning personnel traced the problem to interference produced by the power turbine speed monitor Z253. When the suspect Z253 (subsequently referred to as the "bad" Z253) was replaced, Z226 functioned properly and EPG1 could be started. (As mentioned earlier they had also previously observed a similar situation in EPG2 where the Power Turbine backup overspeed monitor Z353 had reacted incorrectly to an interference-producing power supply in the vibration monitor Z184.)

In the course of the investigation reported here and which centred mainly on the interaction between Z226 and Z253, noise could be observed on both the 24-Vdc and the speed signal wiring of the Diesel speed monitor Z226. The power supplies Z200, Z203 and Z205 (dc/dc converters) were also checked for their contribution to the noise on the 24-volt system.

As recorded in the Appendix, the noise level at the signal input of Z226 was found to be rather low with a "good" Z253 installed. However, when the "bad" Z253 was installed, the noise level on the signal as well as 24-Vdc wires

increased sufficiently for the Diesel monitor's relay K1 to chatter. When a 10-μF capacitor was installed across the 24-Vdc terminals at TB240 and TB241, the noise level was reduced sufficiently for Z226 to stop chattering.

Laboratory tests described in the Appendix were carried out to determine the difference in the noise produced by the "good" and the "bad" Z253s and their effects on the Z226. The "bad" Z253 produced wavebursts of up to 500 kHz which could not be observed with the "good" Z253. It appears that it is the wavebursts that affect the Z226. Another test that superimposed a high-frequency square-wave on the 24 Vdc caused the Z226's relay K1 to drop out, confirming a sensitivity to high frequencies on the dc supply. This sensitivity was enhanced (ie made more sensitive to interference) when the in-line filter was connected between the Z226 and the cable plug. Instead of say 300 kHz causing K1 to drop out, only about 350 Hz were needed, albeit at a higher amplitude.

The reason for the increased sensitivity of the Z226 with the in-line filter in place is the fact that according to SOLAR drawings there appears to be a connection between one side of the speed signal input pin D and the negative 24 volt terminal B, via the circuit common. This allows a portion of the noise across the 24 volt supply terminals A and B to appear on the speed signal input via the filtering capacitors in the in-line filter. (The in-line filter has a 7000-pF capacitor between each pin and the shell.)

A common-mode 15-kHz pulse train of about 0.3 V peak-to-peak could be observed on the speed signal wires of Z226. This pulse signal was found to originate with the power turbine speed monitor Z353 which is mounted at the power turbine.

None of the noise observed on the 24-Vdc electronic bus wiring of EPG1 appeared to be due to the dc/dc converters Z200, Z203 and Z205.

3.2 Emergency Power Generator No. 2

The speed monitors (eg. Z253, Z283 and Z251) were observed to have some noise on the 24-Vdc supply bus from which they were energized, but not of sufficient magnitude to cause problems. The noise observed on the speed signal cables and coming from the monitor speed-signal inputs was similar to that observed across the 24-Vdc bus and appeared to be coupled onto the speed-signal cables via the in-line filters connected between the cable-plugs and the speed monitors. (All wiring connections to each speed monitor are by means of a single cable plug.)

It was noted that the bulk of the noise had a 15-kHz component. This noise was traced to the three dc/dc converter-type power supplies Z200, Z205 and Z203, each contributing varying amounts. Z200 was the main contributor and Z203 the least. (Z204 is not energized from the 24-Vdc bus and hence is not a contributor.) By experimentation it was determined that the noise voltage spikes could be reduced in level by about a factor of ten by applying filtering to the 24-volt inputs to these three power supplies. For Z203 and Z205 a single 20-μF capacitor sufficed as the filter. (More elaborate filters did not produce any additional improvement.) For Z200 a balanced pi section LC filter was required, consisting of a 20-μF shunt capacitor, followed by a pair of series 1 mH inductors and a final 5-μF shunt capacitor.

4.0 DISCUSSION OF FINDINGS

Noise was observed on all wiring associated with the "electronic bus" of the general 24-Vdc bus. This noise voltage is the combined effect of the impulsive-type of load current of the dc/dc converters and the relatively high impedance of the 24 Vdc wiring. There is no single source for the noise but is the sum total of that produced by several monitors and dc power supplies. Noise peaks on the 24-Vdc bus were observed to exceed 5 volts.

Presently this noise does not seem to cause any problems, but the situation could be marginal. It appears that a change in the noise frequency spectrum is sufficient to cause malfunctions, as evidenced by the observations involving the "bad" Z253 and the "repaired" power module in Z184 affecting the speed monitors Z226 and Z353 respectively. It is interesting that only Z226 and Z353 were affected by the higher noise levels. Both are of similar design but differ from the remaining speed monitors which are like Z253.

The sensitivity of Z226 (and Z353) to noise on the 24-Vdc supply appears to be enhanced (ie made worse) by the in-line filters. The reason for this greater sensitivity is believed to be an internal connection between the negative 24-Vdc terminal A of the monitor and the signal input terminal D, thereby reducing the effectiveness of the in-line filter. These filters are not shown on the drawings that were available during the investigation. They may have been added as a blanket measure by the manufacturer when noise problems occurred. The sensitivity of Z226 (and perhaps also of Z353) to noise on the 24-Vdc bus was demonstrated in the laboratory as well as the increase in noise sensitivity due to the in-line filter. The fact that Z226 is not served well by this filter seems to confirm that the filters were included as a matter of general principle for noise reduction, rather than to serve a particular and demonstrated need. This opens the question as to whether some or all of the in-line filters should be removed.

Laboratory tests demonstrated that the Z226 speed monitor could be made to malfunction by merely coupling noise on the 24-Vdc bus such as generated by Z253 into the speed

signal input, while this test failed to cause a Z253 to malfunction. The same tests also demonstrated that the in-line filter renders the Z226 more sensitive to noise. It is thought that the Z253's better immunity to noise on the speed signal input compared to that of the Z226 is due to the fact that the signal input is completely isolated from the supply, thereby providing a better common-mode rejection. From the drawings available during the investigation and purported to represent the circuitry of Z226 and Z353 it appears that the manufacturer provided little or no measures for noise suppression.

The facts that one speed monitor changed the pattern of the noise it puts on the 24-Vdc bus and that a repaired power supply module in the vibration monitor generated noise that formerly was not observed, together raise the question about what changes occurred in the dc/dc converters since their original manufacture to make their noise worse. This question should be put to the manufacturer, along with a request for proposed measures that will prevent a similar noise build-up in other good units.

In general the electronic control system is considerably noisier than one would like to see. A different design approach conceivably could have avoided the noise problems that have happened or still could occur. If the monitors' power supplies were of the linear type, the bulk of the noise on the 24 Vdc bus would not exist. Galvanic isolation between signal and 24-Vdc inputs could have been provided by means of transformers or linear optical couplers. The great demands put on the regulation of the 24-Vdc bus by the "peaky" dc/dc currents would have been avoided and the only noise to be concerned about would have been of a transient nature that with existing techniques could have been coped with more easily. From the bench test observations it can be concluded that the noise problem would exist even without the relatively high impedance imposed by the 300-metre cables. The current pulses due to the various dc/dc converters would seem to be too severe for the design and layout of the control system. The wiring methods, wire sizes etc. as used in the control cabinets just have too high an impedance for adequate voltage regulation.

5.0 SUMMARY

5.1 Noise spikes are present on the 24-Vdc Electronic bus throughout both EPG control cabinets. These spikes, which are typically up to 5 Volts peak-to-peak and can be higher, are caused by current spikes at the inputs to dc/dc converter-type power supplies (Z200, Z203 and Z205 as well as the power supply sections of the Z253 speed monitors) being converted to voltage spikes by the relatively high impedance of the 300-metre 24-Vdc battery cables. (Laboratory tests have indicated that there could be a noise problem even if the battery cables were much shorter.) The size and nature of both the current spikes, as well as the resulting voltage spikes, vary somewhat from point to point within the cabinets, depending on the circuit configuration.

5.2 Despite the presence of these noise spikes throughout the cabinets, the recent speed monitor maloperations have only involved the Z226 speed monitor in EPG1, and even then only when one particular Z253 speed monitor (termed the "bad Z253") was present. With the bad Z253 present the noise amplitude on the 24 Vdc bus was typically up to three times higher than when it was replaced with a good unit. Also, the bad Z253 was found to generate bursts of high frequency oscillatory noise (up to 500 kHz) coincident with each of the noise spikes. Since laboratory tests have showed that the Z226 is particularly sensitive to high frequency noise, it is possible that it is oscillatory noise that was causing the maloperations, rather than just the somewhat higher amplitude spikes.

In all cases at site the maloperations of the Z226 in EPG1 took the form of one of the relays operating or chattering during a time when it should have remained stationary. No maloperations of any of the other speed monitors were observed although it was reported that there had earlier been a problem with the Z353 speed monitor caused by noise generated by the vibration monitor's dc/dc converter. This particular problem had been solved by installing a capacitor across the 24-volt input to the dc/dc converter.

5.3 The erroneous operation of the Z226 speed monitor appears to be caused by the noise on the 24-Vdc bus being coupled capacitively into its input and appearing as an erroneous frequency signal. Capacitances as low as 50-pF (between the 24-Vdc bus and the signal input) are sufficient for this to take place. The coupling process is enhanced by the fact that in the Z226 one side of the signal input is connected to the negative side of the 24-Vdc supply. As a result, any noise on the 24-Vdc supply will tend to be converted into a normal-mode input signal. The in-line filter which is currently used on all speed monitor connectors is one means by which the foregoing capacitive coupling can occur. This is because the filter consists of approximately 7000 pF of capacitance between every pin and common which, because the common point is ungrounded, is effectively equivalent to 3500 pF between each pair of pins.

The foregoing comments also apply to the Z353 speed monitor which has a similar design.

The Z253 speed monitors are significantly less sensitive to this type of noise because their input circuitry is floating with respect to the 24-Vdc supply, so that the coupled noise tends to be balanced and therefore not converted into a normal-mode input signal. Also, the Z253 speed monitors appear to have some degree of internal filtering to improve the immunity to noise on the 24-Vdc bus, whereas the Z226 appears to have none.

5.4 Although maloperations have recently only been observed on the Z226 and only when the "bad" Z253 was present, there is no guarantee that the noise levels are not on the threshold of causing other problems, even without the bad Z253 present. Also, since the mechanism by which the bad Z253 became bad is not currently known, there is no assurance that other Z253 units will not "go bad" as well.

5.5 The noise amplitude on the 24-Vdc bus can (in at least the case of EPG2) be reduced by a factor of about ten by a combination of an LC filter on the Z200 dc/dc power supply input and capacitors on the Z203 and Z205 supplies. Further improvements may be possible by applying capacitors directly across the 24-volt input terminals of the speed monitors. In a laboratory simulation of the actual on-site arrangement, it was found that the Z226 speed monitor could be made immune to any kind of applied noise, including the "bad" Z253, by connecting a 0.1-μF capacitor directly across its 24-volt terminals.

6.0 RECOMMENDATIONS

The results of this investigation, as summarized in the foregoing, would suggest the following course of action to deal with the noise problem in the EPG control system. These measures will not eliminate all possibility of malfunctions due to noise but could reduce the likelihood of such malfunctions to a level similar to the likelihood of other types of malfunctions.

6.1 The "bad" Z253 speed monitor should be left out of service until the manufacturer can positively identify and rectify the mechanism for it generating the observed excessive amplitude of noise spikes, as well as high frequency oscillatory bursts. (Avoiding using the "bad" Z253 could, by itself, be a complete solution to the noise problem since no speed monitor malfunctions have recently been observed without the "bad" unit present. However, the noise could still be on the threshold of causing problems. Also it is possible that the present "good" Z253 units could become bad.)

6.2 The findings of this investigation should be conveyed to the manufacturer of the EPG control system, who should then be asked either to recommend modifications to the system to eliminate the problem or else provide solid reasons for why no modifications are needed. In either case, answers should be sought to the following specific questions:

- What is the mechanism for the excessive noise being applied on the 24-Vdc bus by the "bad" Z253 unit?

- What is the likelihood of the same mechanism developing in other Z253 units? If this likelihood is significant, what steps could be taken to reduce it?

- What filtering or modifications, if any, should be applied to the control cabinet circuitry to minimize the likelihood of this type of noise-induced maloperation from occurring?

- What tests or measurements can be done to verify positively that the noise levels are safely below the levels capable of causing malfunctions?

6.3 Although it is beyond the scope of the present investigation to recommend a particular set of modifications to the EPG control system, it would appear that a satisfactory solution to the noise problem would at least require taking measures to reduce the noise on the 24-Vdc electronics bus. One such measure, which would not require the approval or participation of the manufacturer, would involve the permanent addition of the filtering described earlier in the report for the Z200, Z203 and Z205 dc/dc converter inputs, as well as other filtering on the 24-Vdc bus if needed, so as to reduce the noise voltage spike amplitudes by at least a factor of ten. Since there are essentially no maloperations even without taking this measure, there should then be a safety margin of roughly ten or better.

(One advantage of this approach is that it would benefit not just the devices known to have a problem, ie the Z226 units, but would also improve the noise margins for all other devices on the bus which may or may not be close to the threshold. The alternative approach to reducing the noise on the 24-Vdc bus would be to accept the noise levels as they are and provide suitable 24-Vdc input filtering on every device on the bus that might be affected by the noise. Adding a small foil or ceramic capacitor across the 24-volt input terminals of the speed monitors, especially the Z226 and Z353 units, might suffice. However, with this approach it would be more difficult to establish or even estimate the margin of safety.)

6.4 In addition to the foregoing, there are other measures that could provide additional improvement but would require the participation and/or approval of the manufacturer. These include:

- Removal of some or all of the in-line filter connectors. (This could provide some improvement since it has been shown that in at least some cases the in-line filters can actually exacerbate the noise coupling from the 24-Vdc bus into the speed monitor inputs. However, removing them might well lead to other problems.)

- Application of a ground connection to the common point in the in-line filter connectors.

- Replacement of the Z226 speed monitor (and possibly the Z353 speed monitor) with a more noise-tolerant design such as the Z253.

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APPENDIX

A.1 OBSERVATIONS ON EPG 1 CONTROL SYSTEM

A.1.1 Observations at the 24 volt Input to Z226

The differential-mode noise observed at the 24 Vdc terminals A and B was about 2 to 3 V peak-to-peak. Disconnecting Z253 caused the differential-mode noise level to go up by about 25%. A 10-μF capacitor connected across the 24-Vdc bus at TB240 and TB241 decreased this noise to almost the original level. Increasing the value of that capacitor did not lower this noise further.

A.1.2 Observations at the Speed Signal Input of Z226

Common-mode noise at the speed signal input terminals C&D was about 0.3 V peak-to-peak while normal-mode noise was very low: about 50 mV peak-to-peak. Disconnecting Z253 increased the differential-mode noise about fourfold. The above mentioned capacitor had little effect in reducing this noise level.

A.1.3 Observations with "Bad" Z253 Installed

When the "bad" Z253 was installed, the Z226 chattered. The differential-mode noise on the 24-Vdc supply increased to about 6 V peak-to-peak and on the Z226 speed signal wiring, it increased to 1.6 V peak-to-peak. A 10-μF capacitor across the 24-volt terminals at TB240 and TB241 lowered the 24-Vdc differential-mode noise level to about 4 V peak-to-peak and stopped the chattering of Z226.

A.2 OBSERVATIONS ON EPG 2 CONTROL SYSTEM

A.2.1 Observations at Z226

The noise level on the speed signal wires was measured to be about 80 mV peak-to-peak. When the "bad" Z253 was installed, Z226 in EPG2 also chattered, indicating that the bad Z253 does generate interference of magnitude and frequency that not only equipment in EPG1 is sensitive to. Again as in EPG1, a 10-μF capacitor was effective in lowering the interference level sufficiently for Z226 to stop chattering.

A.3 LABORATORY TESTS ON Z226 AND Z253

Tests were performed in the laboratory to determine the difference in the noise produced by the "good" and the "bad" Z253s and their effects on the Z226. For this purpose, a Z226 and a Z253 were both connected by means of short leads to a common 24-Vdc source. The "good" Z253 was observed to cause an approximately 5-kHz rectangular ripple of 0.5 V peak-to-peak amplitude with 2-V spikes at the rising and falling edges. Z226 did not produce any noise on the 24-Vdc supply on account of its linear-type power supply. The noise from the "bad" Z253 was similar in appearance except the ripple amplitude was double and the spikes were 11 V peak-to-peak, with some of them being actual brief 500-kHz wavebursts. Neither Z253 unit caused the Z226 to malfunction in this test setup.

However, when a small inductance of 250 uH was inserted in series with the two monitors Z226 and Z253, with Z253 being either the "good" or "bad" version, the spike amplitudes became 35 and 70 V peak-to-peak for the "good" and "bad" Z253, respectively. The waveburst amplitude and duration increased to 50 V and 100 μs with the waveburst frequency dropping to 250 kHz. This noise caused Z226 relay K1 to drop out. Relay K2 was not affected.

The "good" Z253 could not be made to cause the Z226 to react, even when the series inductance was increased to 1750 μH. Z253 spikes increased to 45 V peak, but wavebursts were not produced.

From these tests it appears that Z226 is sensitive to high-frequency ac signals on the 24-Vdc supply. A test was made to confirm this sensitivity. It was found that it could be made to drop out K1 with noise frequencies above 200 kHz and amplitudes of about 10 V. It was observed that relay K2 would tend to drop out too when the frequency was slightly increased above the drop-out point of K1.

A simple test was made to assess the relative sensitivity of the Z226 to noise by coupling the 24-Vdc bus noise via a capacitor to the speed signal input. For this purpose, the dc supply terminals of one Z226 and the "good" Z253 were connected in parallel and energized from a 24-Vdc supply via 2 conductors of a 9-metre long cable (Belden No. 9434, 50 conductor, AWG22). With the in-line filter on Z226, a capacitor of only 50 pF was sufficient to cause Z226 to de-energize its relay K1, while without the in-line filter, 250 pF were needed. This contrasts with the observations made with the Z253 where a 22,000-pF capacitor between 24-Vdc bus and speed signal input could not cause Z253 to react to the bus noise. This simple test indicated the relatively high noise sensitivity of Z226 compared to Z253.